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Global Positioning System Runway Incursion Program Static Ground Tests

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Carl Caruso

May 1992

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16. Abstract

This report describes ground tests of the Global Positioning System (GPS) in the terminal area at the Atlantic City International Airport. The purpose of the Runway Incursion Program is to investigate the application of GPS as a navigation aid to allow the pilot to safely traverse airport taxiways and runways under poor visibility conditions. The primary objective of the tests was to resolve the critical issue of differential GPS accuracy as a function of the differential update rate.

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EXECUTIVE SUMMARY

This technical note describes ground tests conducted by the Federal Aviation Administration (FAA) Technical Center to investigate the potential use of the Global Positioning System (GPS) as an aid to the pilot navigating on airport taxiways and runways, especially under conditions of poor visibility.

The primary objective of the tests was to determine what type of horizontal navigation accuracy could be obtained, with a single differential position correction to the receiver, over a finite period of time required for an aircraft to taxi between the ramp and the runway threshold.

Two Motorola Eagle GPS receivers and two Motorola Mitrek very high frequency (VHF) radios were used to implement a static differential mode of operation. The master station, located on the hangar roof, transmitted differential position corrections to the remote station located at a remote survey point.

The four-satellite, three-dimensional (3D) position solution was recorded on a computer at a rate of 1 hertz (Hz), and then reduced and analyzed on a VAX-750 microcomputer. Horizontal error, horizontal dilution of precision (HDOP), and the 3D error components of latitude, longitude, and altitude were plotted as a function of time. A statistical analysis was done on the errors.

The results indicated that differential GPS (DGPS) can provide accuracy of 1 meter (2D rms), or 0.6 meter (CEP), if corrected every 5 minutes. This may be sufficient for GPS to act as a sensor for a runway incursion system.

INTRODUCTION

OBJECTIVE.

The purpose of the Runway Incursion Program (RIP) is to investigate the potential application of the Global Positioning System (GPS) as an aid to the pilot navigating on airport taxiways and runways. The ground tests performed at the Federal Aviation Administration (FAA) Technical Center were designed to resolve the critical issue of DGPS accuracy as a function of the differential update rate. The primary objective of this report is to investigate the horizontal accuracy of Differential GPS (DGPS) over a wide range of update rates. The secondary objective is to recommend appropriate update rates for horizontal navigation in the terminal area.

BACKGROUND.

The GPS is comprised of three major segments:

1. The control segment consists of five monitor stations and the master control station. The function of the monitor stations is to track the orbits of all GPS navigation satellites on a daily basis. The master control station uses this tracking data to precisely determine satellite orbital parameters, or ephemeris data, to be uploaded to individual satellites for retransmission to the user.

2. The user segment includes all GPS receivers and associated user-equipment. All GPS receivers employ a satellite ranging algorithm called passive multilateration. The receiver measures the transit time of the GPS signal in space using code correlation techniques. The receiver code is time shifted until maximum correlation with the satellite code is achieved. This time shift, when multiplied by the speed of light, will yield an initial estimate of the range to a satellite. This initial range estimate is referred to as a pseudorange because it contains errors such as propagation delay and clock bias. The receiver attempts to correct these errors using the ephemeris data received from the satellite.

3. At the time of this writing, the space segment consists of 5 Block I satellites and 10 Block II satellites. Current plans call for a Block II constellation of 24 satellites by 1993, with an interim 21-satellite constellation to be implemented as soon as possible. The satellite orbits have a period of approximately 12 hours, with satellites appearing over the same location about 4 minutes earlier each day. The satellites receive data from the control segment and each satellite continuously transmits a navigation message to the user segment.

The satellites transmit on two L-band carrier frequencies. The L1 and L2 carriers are centered at 1575.42 and 1227.6 megahertz (MHz), respectively. The L1 carrier is modulated with two waveforms; the course acquisition (C/A) code at a chip rate of 1.023 MHz, and the precise (P) code at a chip rate of 10.23 MHz. The L2 carrier is modulated with the P-code only. The C/A code is available to all users, but can be corrupted by means of selective availability (SA). The P-code is specially encrypted for military use only. SA is accomplished by introducing errors into the ephemeris data contained in a satellite's almanac, and by manipulating the frequency of the

satellite's clock. The implementation of SA by the control segment can degrade receiver accuracy by a factor of 10.

With the current 15 operational satellites, three-dimensional (3D) navigation can be accomplished about 12 hours per day during selected windows. A 3D navigation window is a period of time during which four satellites are visible, with a position dilution of precision (PDOP) less than six. A two-dimensional (2D) navigation window is a period of time during which three satellites are visible, with a horizontal dilution of precision (HDOP) less than four.

RELATED DOCUMENTS.

An Analysis of GPS Ground Navigation in the Terminal Area, Deering Systems Design Consultants, March 1991.

Persello, L. Frank, Differential GPS Terminal Area Test Results, November 1990.

Introduction to NAVSTAR GPS, NAVSTAR GPS Joint Program Office, June 1987.

Motorola Mini-Ranger User's Manual, Motorola Incorporated, March 1987.

DISCUSSION

EQUIPMENT DESCRIPTION.

TEST VEHICLE. The FAA test vehicle was equipped with 60 hertz (Hz) power, a very high frequency (VHF) whip antenna, a ground plane for the external L-band antenna, and mounting hardware for the preamplifier. The L-band antenna was located to the extreme rear of the vehicle, 167 inches above the ground to avoid any shading problems, and just behind the rear bumper to facilitate accurate positioning of the antenna over a survey point. The external preamplifier was located directly beneath the antenna to minimize delay and attenuation of the L-band signal.

GPS RECEIVER. The master station, located on the hangar roof, was equipped with a Motorola Eagle GPS receiver, a receiver control computer, and a Motorola GPS antenna/preamplifier. The antenna was mounted on a ground plane to optimize the antenna radiated pattern. A Compaq 286/SLT laptop was used for the receiver control computer. The antenna/preamplifier contains a right hand circularly polarized (RHCP) microstrip antenna, a preamplifier and an intermediate frequency (IF) section. A block diagram of the Eagle GPS receiver is shown in figure A-1 in the appendix.

The remote station, located in the FAA test van, was identical to the master in its configuration, except that an external antenna was used with the Motorola GPS preamplifier, and a Tandy TRS80/102 was used for the receiver control computer. The preamplifier was identical to the one used in the master station, except that it is configured for use with an external antenna. A block diagram of the remote station is shown in figure A-2 in the appendix. Technical specifications for the Motorola Eagle GPS receiver and antenna/preamplifier are shown in figure A-3 in the appendix.

VHF DATA LINK. Differential corrections are sent via data link from the reference receiver to the remote test site. A Motorola Mitrek mobile radio with a carrier frequency of 164.6375 MHz, and a 1200 bps modem with RS232 serial interface were used for this purpose. The VHF data link components and interconnections are also shown in figure A-2.

DATA COLLECTION SYSTEM.

The data collection system utilized a Compaq 286/SLT laptop computer equipped with RS232 serial interface and Smart Term ST240 communications software. Data were recorded from the receiver control port output, as shown in figure A-2.

DATA REDUCTION/ANALYSIS.

Data reduction was accomplished on a VAX-750 microcomputer, using customized software written in C. The test data were first downloaded to a Compaq Deskpro 386/20e personal computer (PC) for inspection, and then downloaded to the VAX-750 for editing. Latitude, longitude, and altitude were converted from degrees to meters before comparison to the truth source and computation of the respective errors and statistical parameters.

TEST PROCEDURES

BENCH TESTS.

Bench tests were performed to insure the proper functioning of all hardware and software components, and also to experiment with different update rates. No analysis of the data was performed other than to examine it for anomalies.

GROUND TESTS.

The update rates considered for ground tests were 5, 10, and 30 minutes. Ground test data were recorded at two remote survey points during the period beginning February 4 and ending February 14, 1991. A total of 24 test runs were recorded at two remote survey points over a period of 5 days.

The Motorola Eagle GPS receiver has four parallel channels for digital signal processing, allowing it to track up to four satellites, the minimum required for a 3D position solution. During normal operation, the receiver will always attempt to track the best four satellites, based on PDOP computations. When the receiver is in the process of switching satellites on one of the four channels, it operates in a 2D mode with three satellites.

Although a horizontal position solution is provided with three satellites in the 2D navigation mode, the best accuracy will always be obtained with a four-satellite position solution. For the purposes of this experiment, it was necessary to track four satellites continuously during each test run. Therefore, a manual satellite selection algorithm was used.

RESULTS

BENCH TESTS.

Bench test results indicated that the unit was operating normally and no anomalies were detected. No analysis of bench test data was done.

GROUND TESTS.

Ground test data presented here includes nine test runs, recorded at two remote survey points over a period of 4 days. HDOP, horizontal error, and the 3D error components of latitude, longitude, and altitude were plotted as a function of time. A statistical analysis was done on the error data as well.

HDOP is a unitless parameter indicating the expected magnitude of errors in the horizontal position solution, based on the relative positions of the satellites being tracked. All errors and statistical parameters are presented in units of meters (m).

Error data computed from the selected test runs are presented in figure 1. The plots are grouped with respect to the test station position. The respective statistical parameters, computed from the error data, are presented in table 1.

CONCLUSIONS

BENCH TESTS.

The results of the bench tests showed the system to be operating normally, with errors in the normal range for static Differential GPS (DGPS).

GROUND TESTS.

The conclusions are based on nine test runs. Four satellites were tracked continuously during each test run. There were no constellation changes during each test run. The results demonstrate a trend that errors increase as a function of time after a single differential position correction to the receiver. Statistically, it is possible to have errors which are larger or smaller than those presented in this report. Based on the small sample of data, the following conclusions can be drawn:

1. A differential update rate of 5 minutes can provide horizontal accuracy on the order of 1 meter 2 distance root-mean-square (Drms), or 0.6 meters Circular Error Probability (CEP).

2. A differential update rate of 10 minutes can provide horizontal accuracy on the order of 4 meters 2Drms, or 2.2 meters CEP.

3. A differential update rate of 30 minutes can provide horizontal accuracy on the order of 5 meters 2Drms, or 2.5 meters CEP.

4. Selective Availability (S/A) has the ability to degrade the accuracy of a receiver by a factor of 10. Therefore, it can be assumed that the runway incursion avoidance techniques described here would be rendered ineffective by the implementation of S/A.

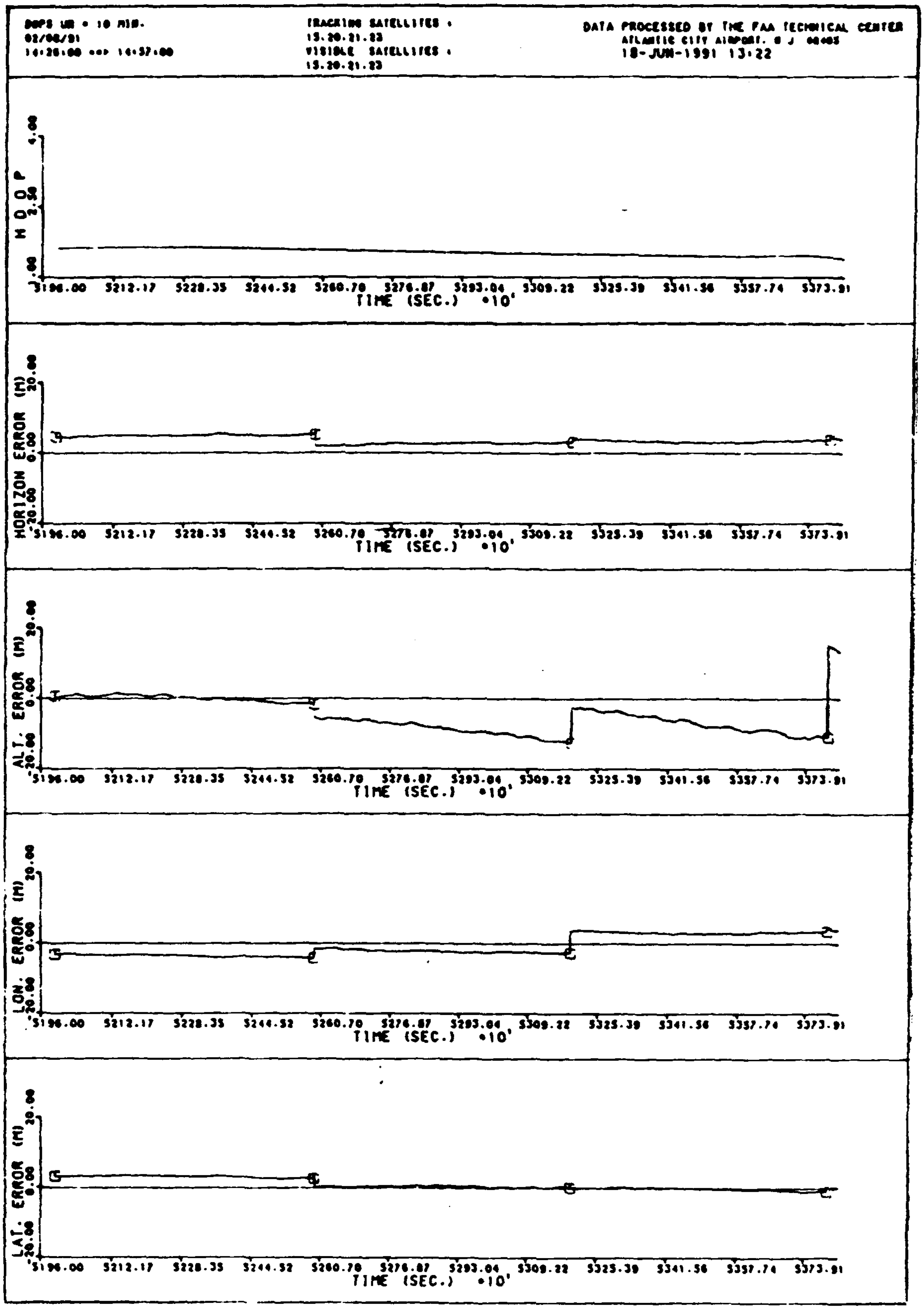

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 1 OF 9)

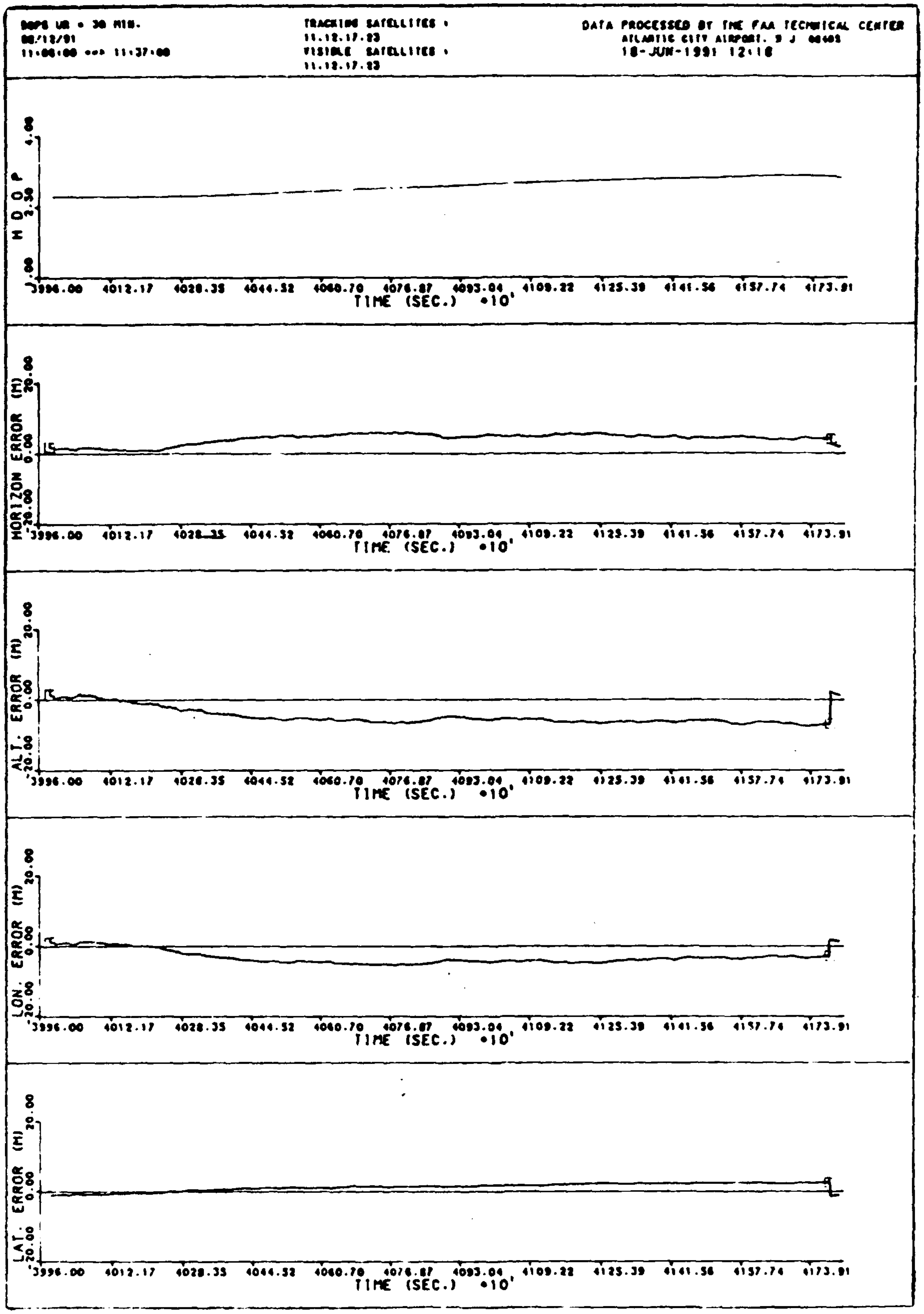

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 2 OF 9)

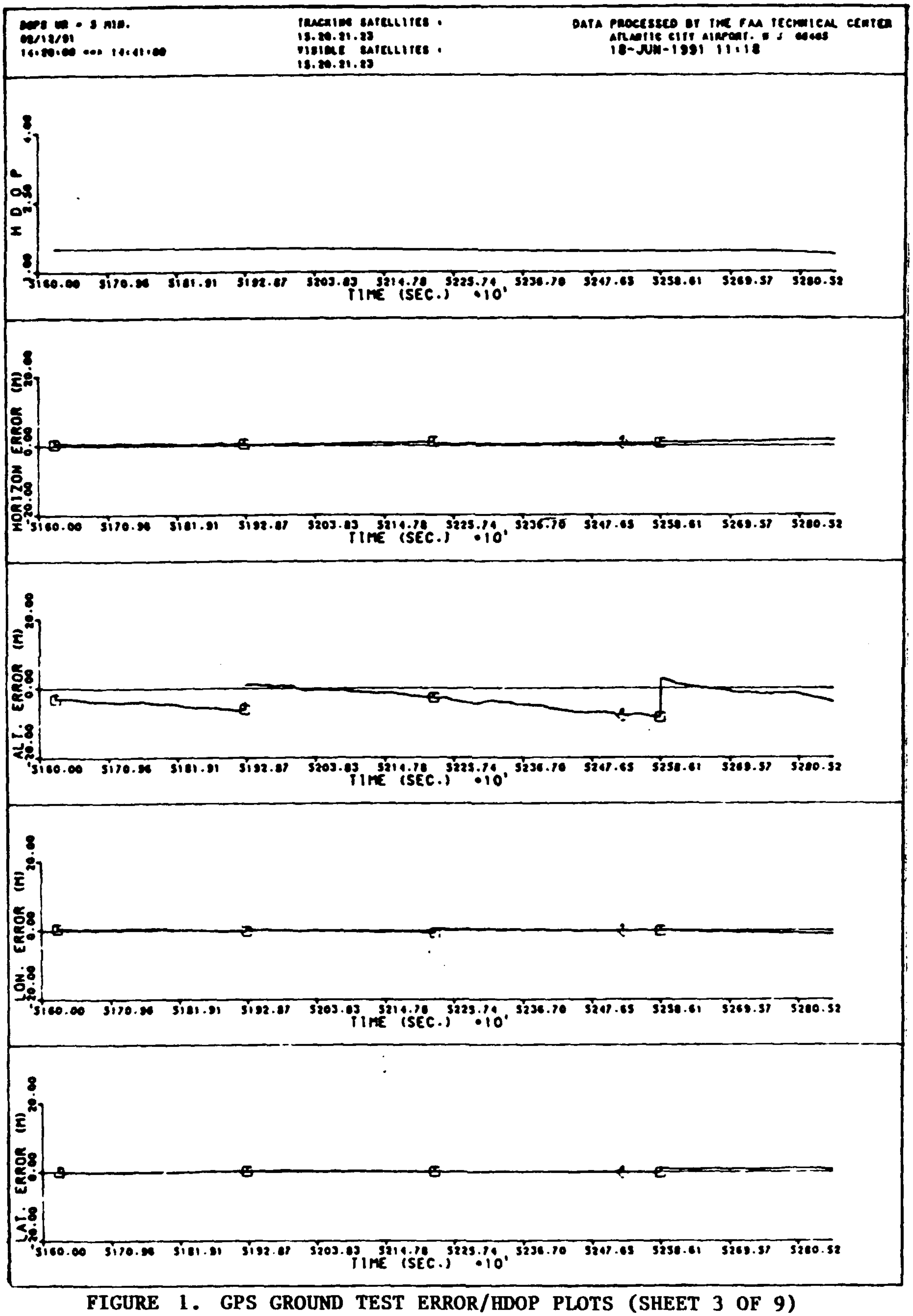

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 3 OF 9)

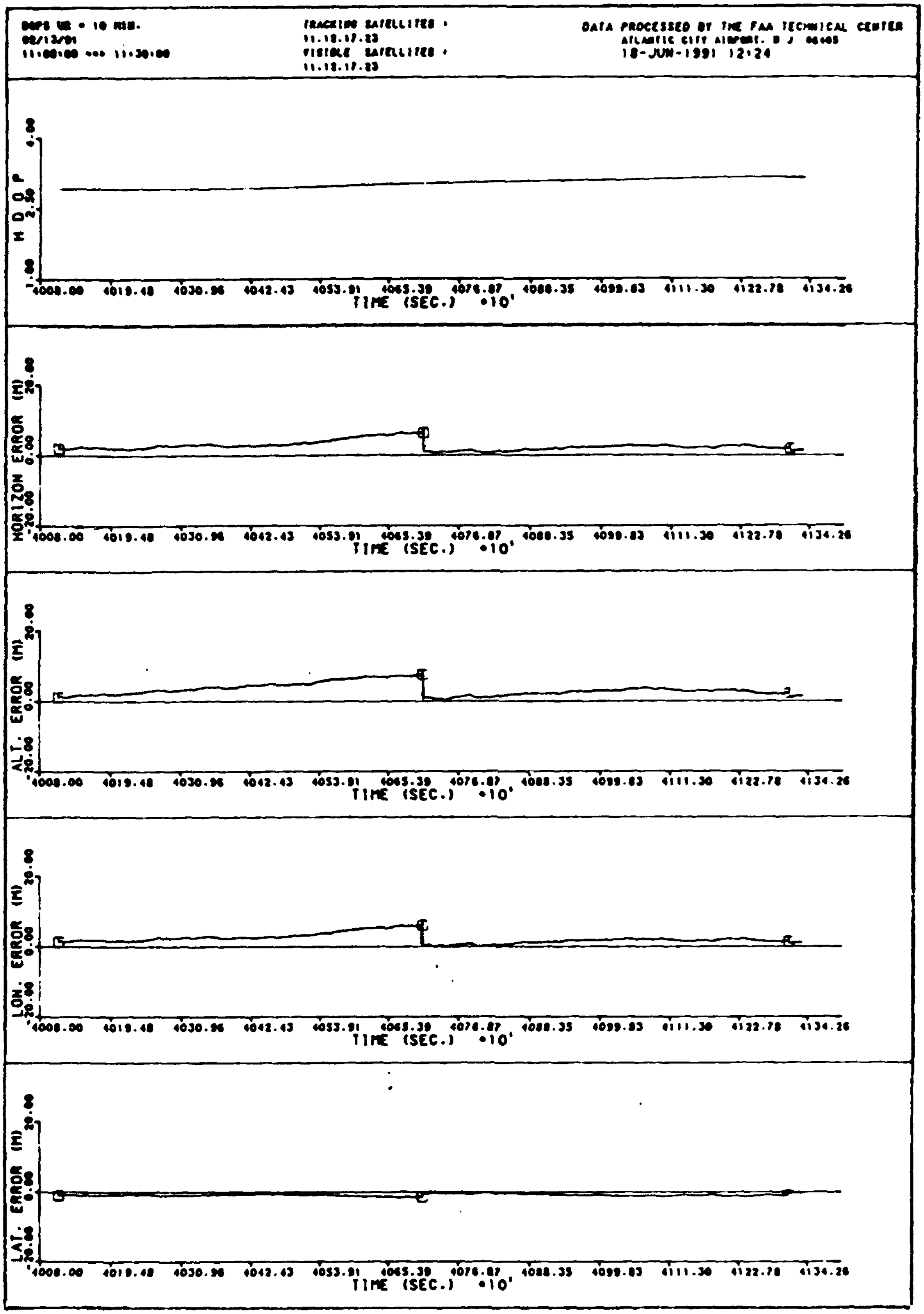

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 4 OF 9)

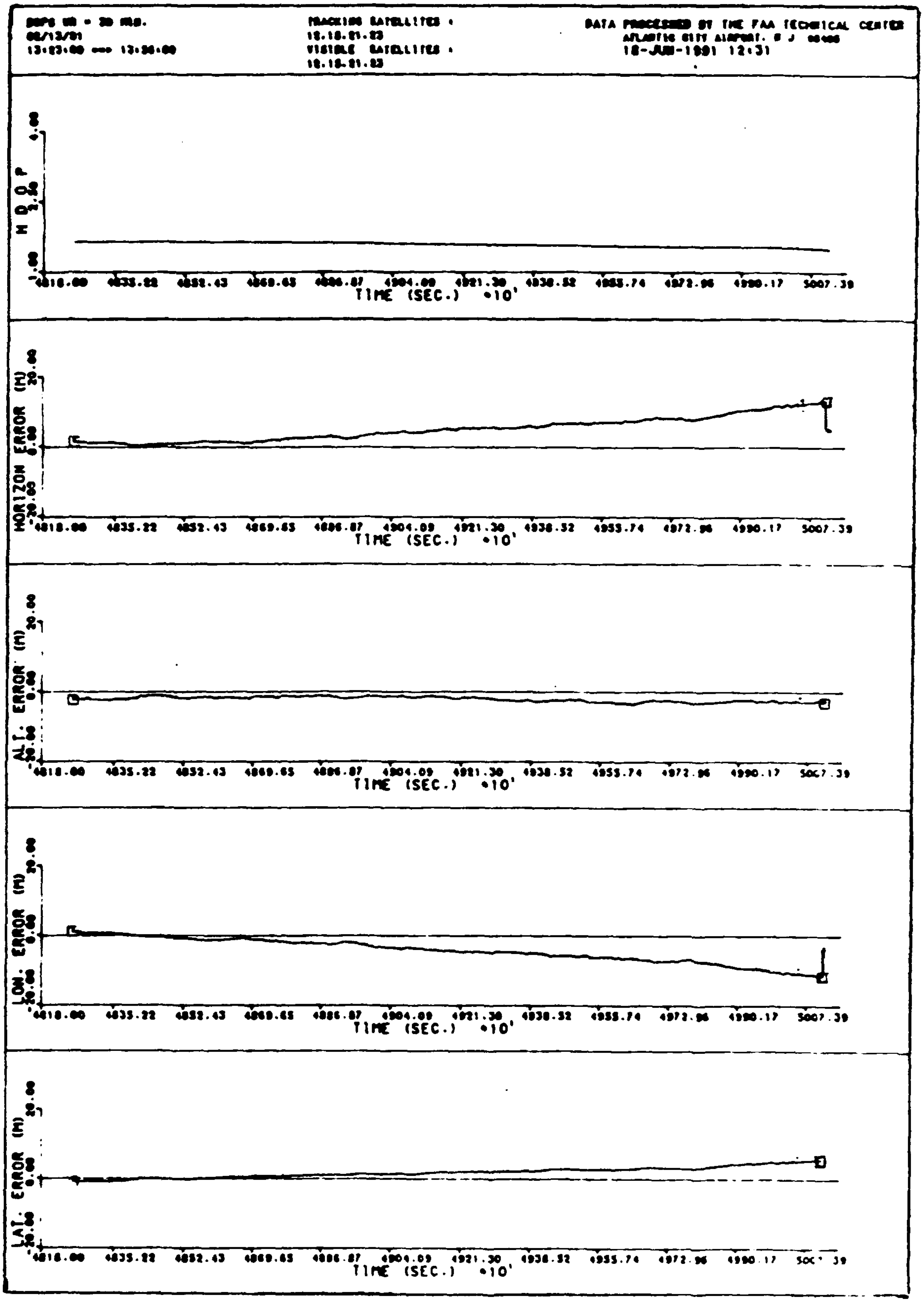

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 5 OF 9)

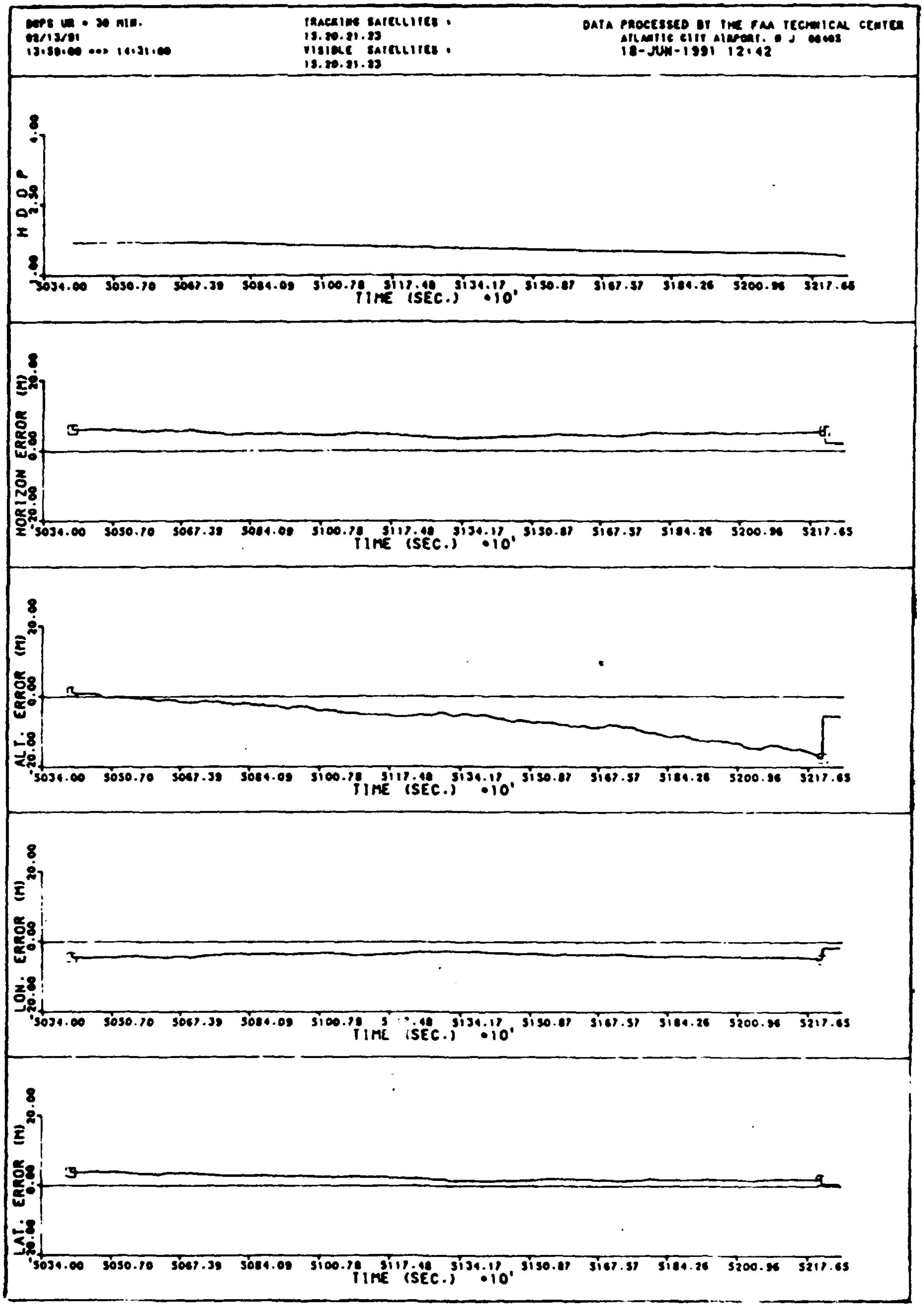

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 6 OF 9)

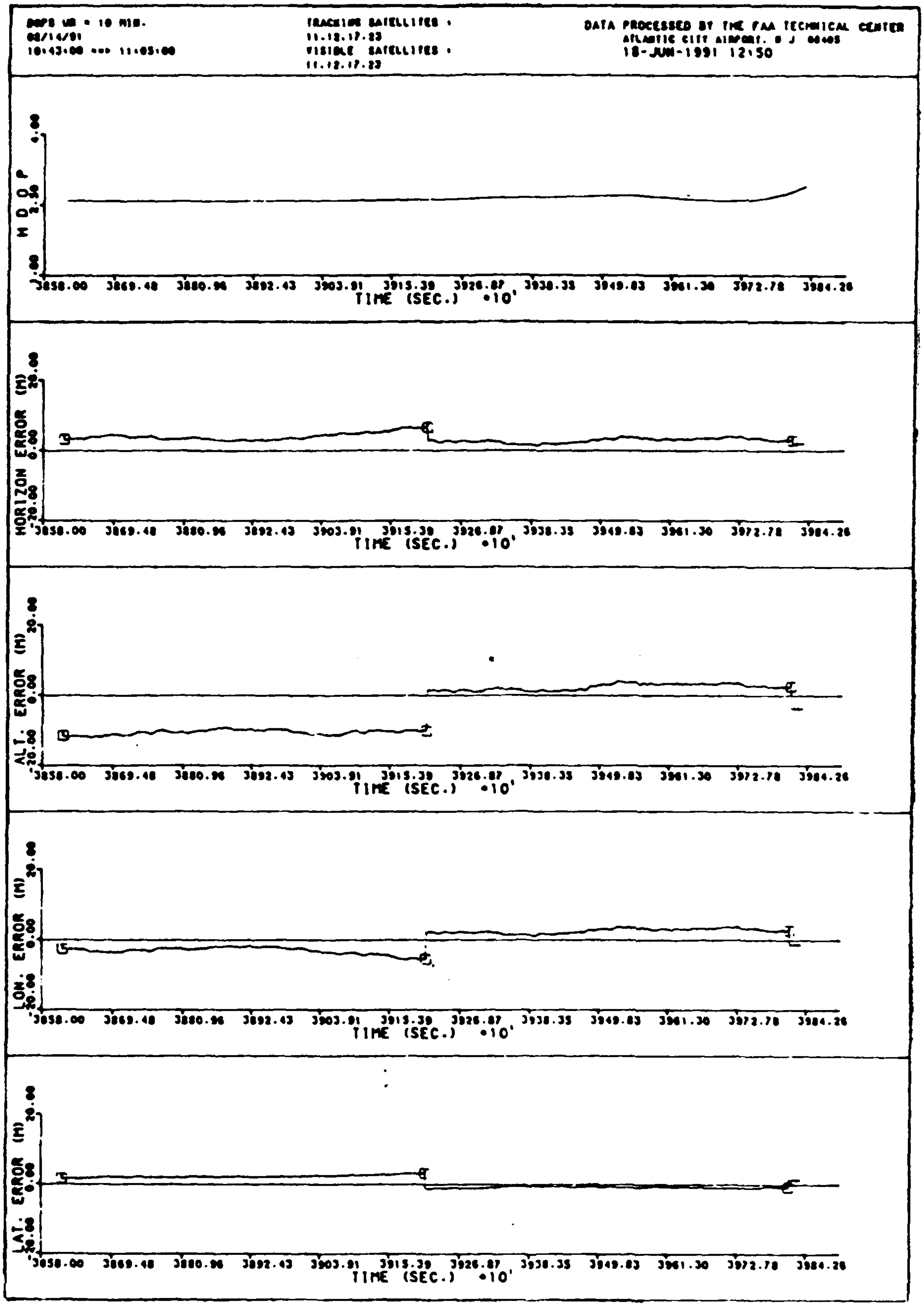

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 7 OF 9)

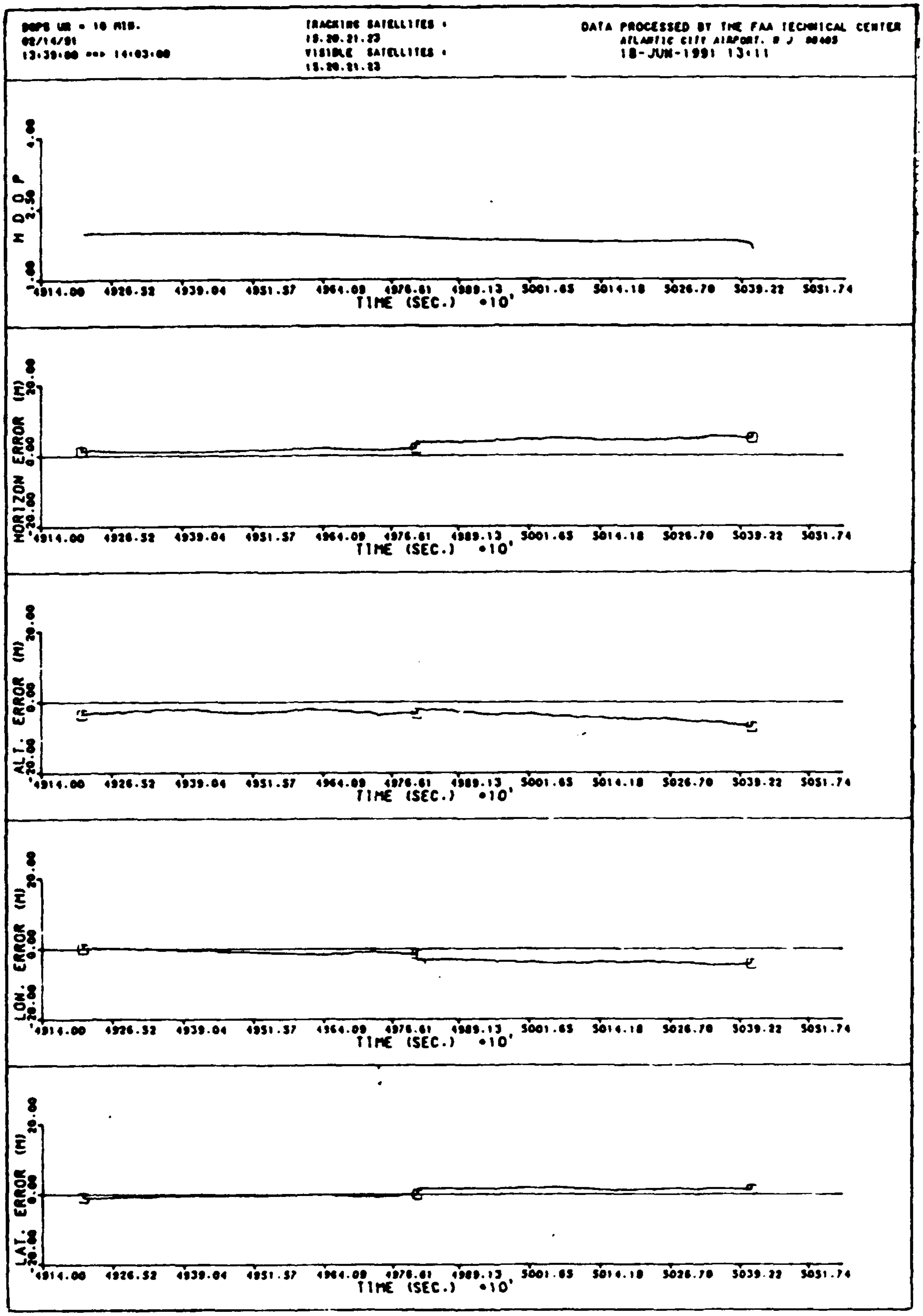

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 8 OF 9)

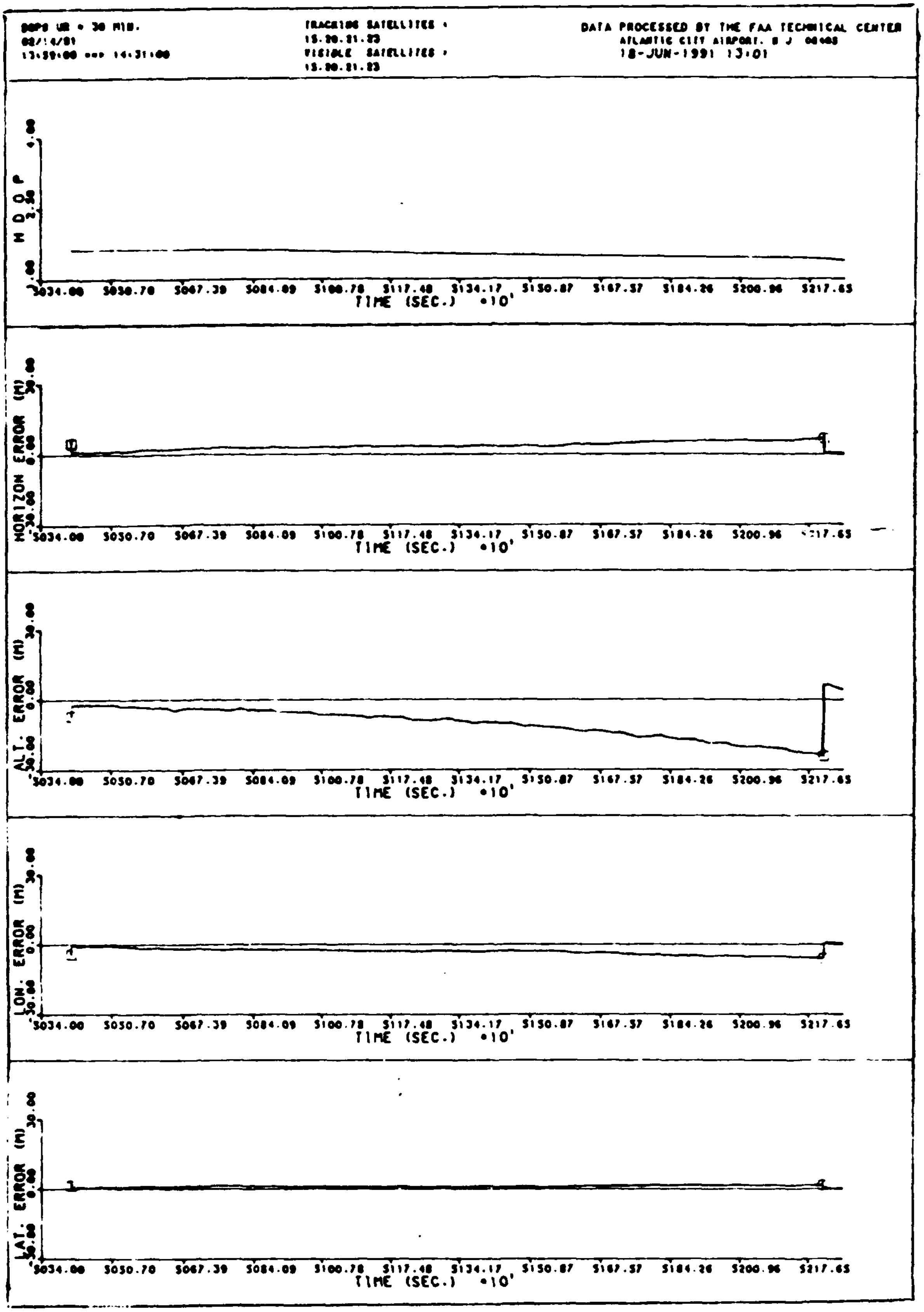

FIGURE 1. GPS GROUND TEST ERROR/HDOP PLOTS (SHEET 9 OF 9)

TABLE 1. INDIVIDUAL GPS GROUND STATISTICS

Filename: 0208STA.10M — Update Rate: 10 minutes

	X	Y	Z
Mean Error........	-0.9617	-3.2837	-1.8199
Standard Dev......	2.2894	5.7562	4.8955

	Lat	Long	Hgt
Mean Error........	1.1028	3.0863	6.1095
Standard Dev......	1.6597	3.1495	7.3620

2Drms.............	5.0347
CEP...............	2.8312
SEP...............	6.6302

(Statistics in meters)
(2010 records)

Reference: Figure 1

Filename: 0212STA.30M — Update Rate: 30 minutes

	X	Y	Z
Mean Error........	1.2620	-4.9567	-2.2408
Standard Dev......	1.6321	5.6038	2.3855

	Lat	Long	Hgt
Mean Error........	1.3652	3.6032	5.0198
Standard Dev......	1.5001	3.9044	5.4128

2Drms.............	5.9152
CEP...............	3.1817
SEP...............	4.9289

(Statistics in meters)
(1824 records)

Reference: Figure 1

Filename: 0212STA.15M — Update Rate: 5 minutes

	X	Y	Z
Mean Error........	-0.2442	-2.4239	-2.0148
Standard Dev......	0.6567	3.0916	2.7560

	Lat	Long	Hgt
Mean Error........	0.3347	0.4696	3.4307
Standard Dev......	0.4158	0.5988	4.1260

2Drms.............	1.0309
CEP...............	0.5973
SEP...............	3.3326

(Statistics in meters)
(1477 records)

Reference: Figure 1

TABLE 1. INDIVIDUAL GPS GROUND STATISTICS (continued)

Filename: 0213STA.11M — Update Rate: 10 minutes

	X	Y	Z
Mean Error........	-0.3539	3.3512	1.1413
Standard Dev......	0.8900	3.7796	1.5116
	Lat	**Long**	**Hgt**
Mean Error........	1.1134	2.1514	3.1469
Standard Dev......	1.1521	2.5619	3.6045
2Drms.............	3.9726		
CEP...............	2.1864		
SEP...............	3.1665		

(Statistics in meters)
(1224 records) — Reference: Figure 1

Filename: 0213STA.31M — Update Rate: 30 minutes

	X	Y	Z
Mean Error........	2.2262	-3.6235	-0.0930
Standard Dev......	2.6861	4.0914	1.0674
	Lat	**Long**	**Hgt**
Mean Error........	1.9662	4.6300	2.2990
Standard Dev......	2.4429	5.6353	2.3889
2Drms.............	8.6861		
CEP...............	4.7556		
SEP...............	4.0184		

(Statistics in meters)
(1866 records) — Reference: Figure 1

Filename: 0213STA.32M — Update Rate: 30 minutes

	X	Y	Z
Mean Error........	0.4030	-6.7168	-2.5159
Standard Dev......	0.5580	7.4814	4.2094
	Lat	**Long**	**Hgt**
Mean Error........	2.1068	3.9102	6.5700
Standard Dev......	2.2378	3.9571	7.9939
2Drms.............	6.4291		
CEP...............	3.6470		
SEP...............	6.2753		

(Statistics in meters)
(1845 records) — Reference: Figure 1

TABLE 1. INDIVIDUAL GPS GROUND STATISTICS (continued)

Filename: 0214STA.10M — Update Rate: 10 minutes

	X	Y	Z
Mean Error........	-0.9841	-3.4904	-2.3043
Standard Dev......	1.1358	7.1081	3.7348

	Lat	Long	Hgt
Mean Error........	1.5554	2.8802	6.4232
Standard Dev......	1.6654	3.0384	7.7395

2Drms.............	4.9001
CEP...............	2.7691
SEP...............	6.1368

(Statistics in meters)
(1221 records) — Reference: Figure 1

Filename: 0214STA.11M — Update Rate: 10 minutes

	X	Y	Z
Mean Error........	1.3675	-3.4248	-1.9858
Standard Dev......	1.4484	3.7756	2.1151

	Lat	Long	Hgt
Mean Error........	1.0061	2.5047	3.5304
Standard Dev......	1.0856	2.9760	3.7372

2Drms.............	4.4800
CEP...............	2.3911
SEP...............	3.7598

(Statistics in meters)
(1201 records) — Reference: Figure 1

Filename: 0214STA.31M — Update Rate: 30 minutes

	X	Y	Z
Mean Error........	0.5139	-7.5623	-5.2740
Standard Dev......	0.6667	9.4666	6.7529

	Lat	Long	Hgt
Mean Error........	0.8028	2.9051	9.4025
Standard Dev......	0.8920	3.3163	11.2578

2Drms.............	4.8567
CEP...............	2.4775
SEP...............	8.6516

(Statistics in meters)
(2389 records) — Reference: Figure 1

APPENDIX

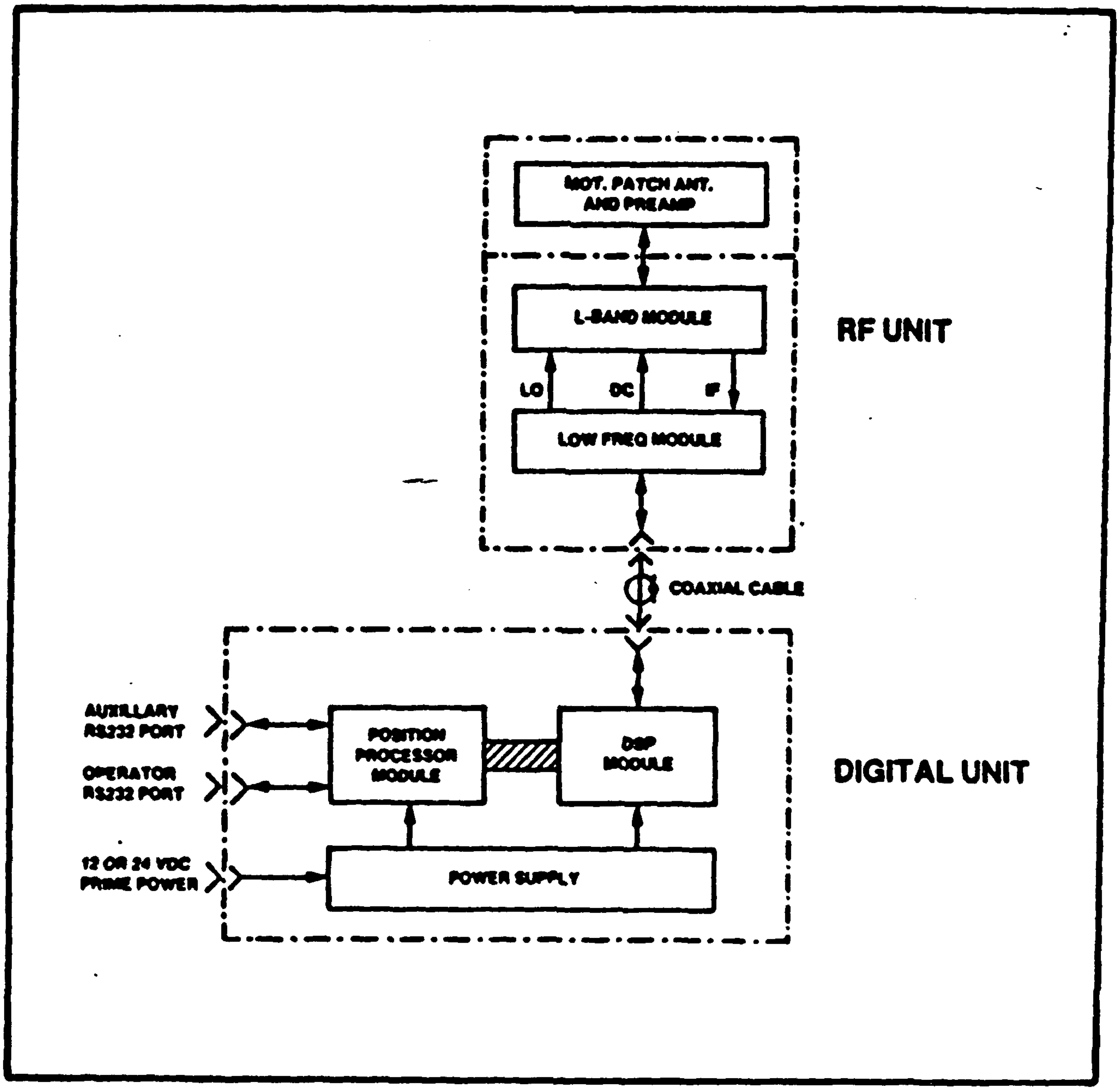

FIGURE A-1. EAGLE GPS RECEIVER BLOCK DIAGRAM

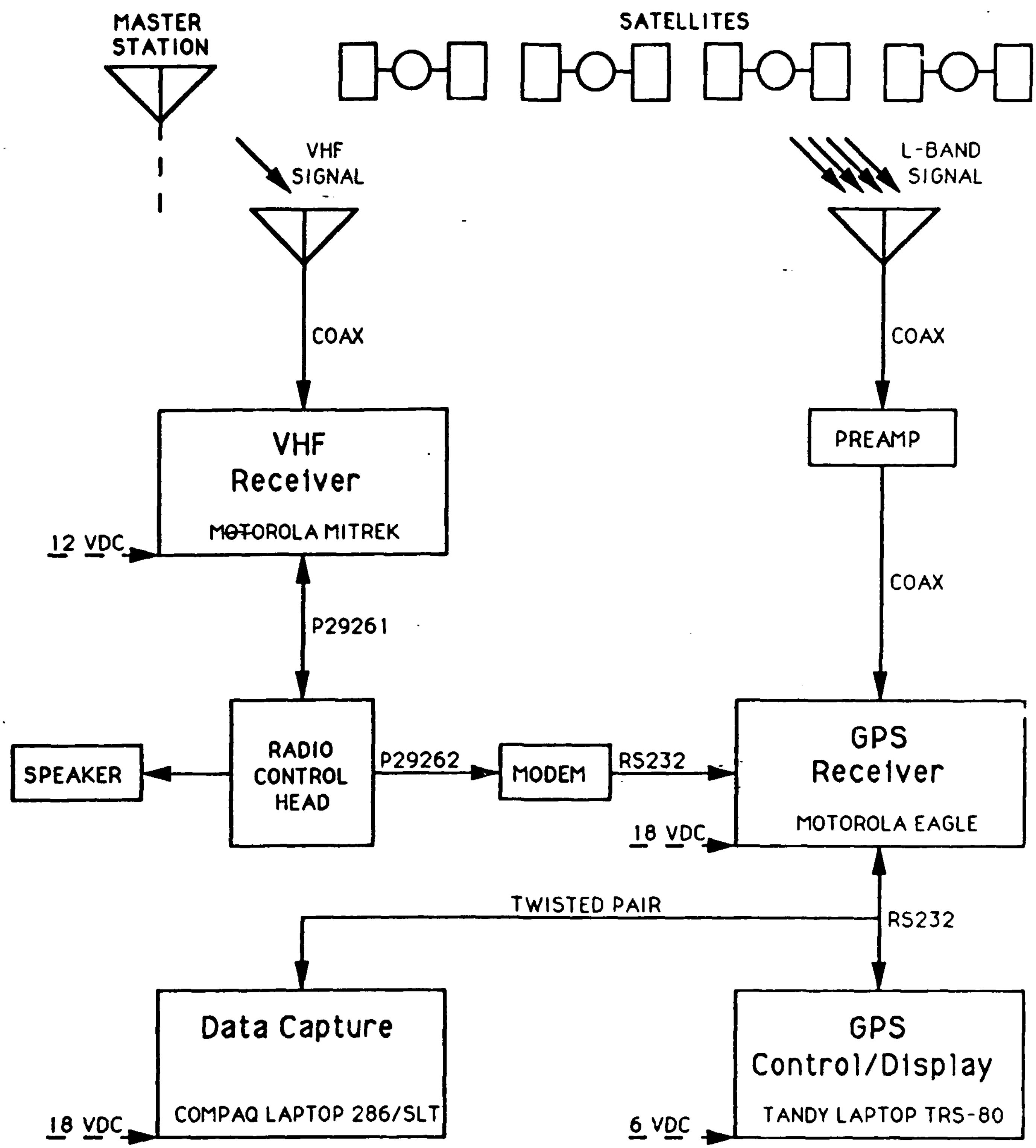

FIGURE A-2. GPS TEST RACK BLOCK DIAGRAM

GPS RECEIVER SPECIFICATIONS

Eagle
GPS Receiver
MINI-RANGER

SYSTEM PERFORMANCE

Receiver Type	4-channel, simultaneous L_1 C/A code carrier tracking
Operating Modes	Autonomous/differential, real-time or post-process
Solution Type	8-state Kalman update
Accuracy Autonomous Differential	Less than 25 meters SEP for GDOP[1]<4 Less than 5 meters SEP[2]
Interrogation time to: First Fix (cold) First Fix (warm with almanac)	 15 minutes maximum 3 minutes maximum
Position/Velocity Update rate autonomous or real-time differential	 1 second
Datum Shift Uses WGS-84 built-in conversions to: WGS-72, NAD '27, et al.	
Dynamic Maximums Velocity Acceleration	 600 knots max 1g max

Note:

1. Assuming Department of Defense does not intentionally degrade the accuracy.
2. Static position accuracy under controlled conditions with post processing and GDOP < 4.

Specifications subject to change upon product improvement.

ELECTRICAL PARAMETERS

Operating Voltages	Optional 18 to 32 volts dc or 10 to 17 volts dc
Operating Power	25 watts maximum (antenna/preamplifier unit powered from receiver)

PHYSICAL PARAMETERS

Size Receiver-Processor (P/N 01-P28923U001) Antenna/Preamplifier (P/N 01-P28924U001) Antenna/Preamplifier to receiver separation	 12 × 7 × 2.23 inches HWD (30.5 × 17.8 × 5.7 cm) (1/4 ATR dimensions) (19-inch rack optional) 4.5 × 4.5 × 2 inches HWD (11.4 × 11.4 × 5.1 cm) 150 feet maximum (46m) RG-142 cable (longer length with optional low loss cable)
Weight Receiver Antenna/Preamplifier	 4.5 lbs (2.0 kg maximum) 3 lbs (1.4 kg maximum)
Temperature Receiver Operating Storage Antenna/Preamplifier Operating Storage	 −20°C to +55°C −40°C to +70°C −40°C to +85°C −55°C to +100°C
Humidity	0 to 90% noncondensing
Shock	15g, 11 ms, 1/2 sine wave
Vibration	1g, 50 to 500 Hz

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FIGURE A-3. EAGLE GPS RECEIVER SPECIFICATIONS